

Design Process of Flight Vehicle Structures for a Common Bulkhead and an MPCV Spacecraft Adapter

Abstract

Design and manufacturing space flight vehicle structures is a skillset that has grown considerably at NASA during that last several years. Beginning with the Ares program and followed by the Space Launch System (SLS); in-house designs were produced for both the Upper Stage and the SLS Multi-purpose crew vehicle (MPCV) spacecraft adapter. Specifically, critical design review (CDR) level analysis and flight production drawing were produced for the above mentioned hardware. In particular, the experience of this in-house design work led to increased manufacturing infrastructure for both Marshal Space Flight Center (MSFC) and Michoud Assembly Facility (MAF), improved skillsets in both analysis and design, and hands on experience in building and testing (MSA) full scale hardware. The hardware design and development processes from initiation to CDR and finally flight; resulted in many challenges and experiences that produced valuable lessons. This paper builds on these experiences of NASA in recent years on designing and fabricating flight hardware and examines the design/development processes used, as well as the challenges and lessons learned, i.e. from the initial design, loads estimation and mass constraints to structural optimization/affordability to release of production drawing to hardware manufacturing. While there are many documented design processes which a design engineer can follow, these unique experiences can offer insight into designing hardware in current program environments and present solutions to many of the challenges experienced by the engineering team.

The first structure presented here is the SLS MPCV spacecraft adapter (MSA) is a primary dry structure that separates the Delta Cryogenic Second Stage (DCSS) from the MPCS (see figure 1). Its geometry is a rear facing conical shape, produced from integrally machined aluminum-lithium 2195 isogrid stiffeners and two single piece ring forgings. This structure performs several functions including primary launch vehicle load carrying, separation of the corresponding interior MPCV and DCSS environments through a spherical cap diaphragm, cable interface panels, access panels, and attachment interfaces for electrical cable wiring harness to span the adjacent structures. Finally, the MSA will be covered with a thermal protection system to protect against extreme external thermal environments experienced due to the variable outer mold line, trajectory and isp.

There were many challenges faced with designing the MSA structure. First, the loads for the MSA; this structure was designed to meet manned flight SLS loads and the non-manned MPCV exploration flight test environments. While this is certainly attainable, it presented challenges for verification, mass and integration. To accomplish the structural sizing of the MSA an evolutionary optimization closed form methodology was used. Margins were written against for dual sets of environments, both the exploration flight test and SLS exploration missions 1. Coupling the environments permitted a significant cost and schedule savings through the use of a single design, that is functional on two different launch vehicles. Secondly, a comprehensive design study was performed on the integral machined grid stiffened pocket sizes with respect to inspection, manufacturing, cleaning and mass. It turned out that the lightest design revealed pocket sizes that

resulted in mildly significant impacts on producibility processes, i.e. the optimal pocket size was on the order of 3.00" in vertical height, while this is indeed achievable with advanced manufacturing processes, cleaning and non-destructive evaluation, it was determined to sacrifice some mass for simplified machining and overall reduced processing time. Third, thermal expansions of dissimilar material presented challenges when using metallic primary structure and a non-metallic thermal barrier between the aft and fwd internal volumes. This nonmetallic diaphragm barrier is designed to carry a slight negative pressure (MPCV side greater than DCSS side). These topics will be discussed greater detail in the paper

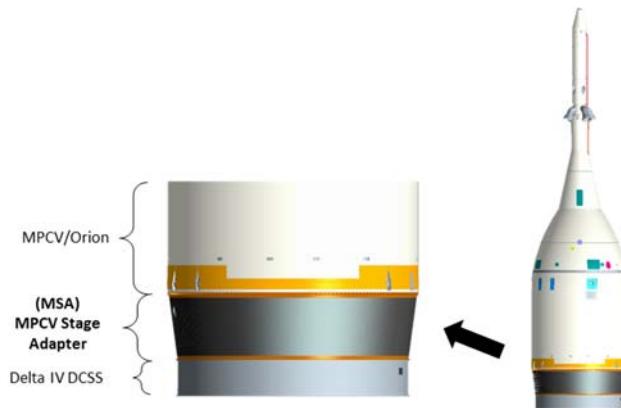


Figure 1: MPCV Spacecraft Adapter

The second structure is the Ares I common bulkhead (CB) (figure 2), it is an interior barrier within a launch vehicle tank assembly that physically separates the fuel and oxidizer. A CB serves as an interface/closeout for the propellant and oxidizer tanks. Such structures are commonly used due to the improved structural efficiency of eliminating a dry structure and decreased overall vehicle length. This results in increased payload capability for the vehicle. Common bulkheads are designed as one of the following, composite sandwich structures, alternate bonded composite domes, grid stiffened domes, or pressure stabilized domes. A composite sandwich consists of two metallic domes bonded to a typically nonmetallic core. There are both elliptical tapered core domes and spherical cap constant thickness domes. The structural configuration discussed here is a bonded composite structure.

As with all designs, there are many challenges, the foremost being with the bonded composite common bulkhead is the severe temperature gradient between the facesheets; this gradient exceeds 530degF across < 2.00 inches. As this is the case, a severe shear stress develops from the thermal expansion/contraction of the metallic facesheets as they are coupled across a nonmetallic core region; additionally managing the heat leak across the CB, specifically for an LOX/LH₂ configuration, is necessary to maintain the propellant quality within the rocket engine start/run box, minimize stratification, preclude LOX icing, and protect against LOX tank ullage decay and reduction of propellant quality. To handle the severe environmental restrictions, a carefully optimized combination of facesheet and core materials and thicknesses was selected. An evolutionary optimization approach was used to accomplish this. The second challenge encountered is the difficulty of holding a bonded tolerance of 0.012" over the entire surface (330 ft²) during the manufacturing process. Bonding the core to the dome plagued previous programs

and has produced major challenges to the Ares program; specifically precision CNC machining and core and dome profiling. Additionally, managing the

Design, analysis and manufacturing of primary structure spaceflight hardware is complex and highly rewarding work to do. It is the intent of this paper to explore the processes from conception or initiation of design concept all the way through fabrication, test and finally flight. This journey of the design and analysis process will be explored in more detail for the examples of the SLS MSA and the Ares CB, specifically design processes will be communicated to help future design of flight hardware.

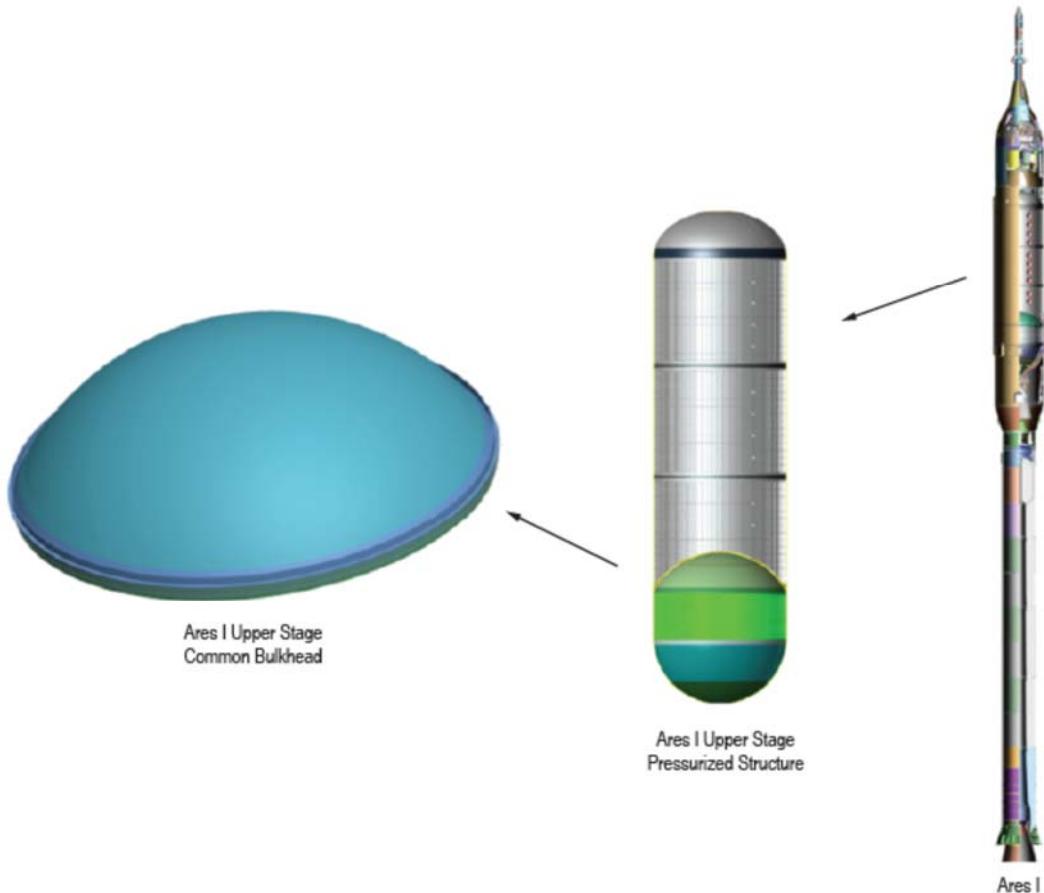


Figure 2. Common bulkhead as part of an Ares I upper stage LH₂/LOX configuration